GEOTHERMAL HEAT PUMP UTILIZATION IN THE UNITED STATES

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Introduction

Air source heat pumps have been used for many years, but due to the constant temperature of ground water, water source heat pumps became popular in the 1970s. This was promoted in part by the National Water Well Association of Dublin, Ohio. Due to cheap drilling methods, earth coupled closed loop heat pump systems gained in popularity in the 1980s. The latter consist of either vertical or horizontal installations of a closed loop heat exchanger. The vertical installation normally uses a 4-inch diameter hole, in which two one-inch diameter plastic pipes are placed and grouted. Drilling and piping costs are around $2.50 per foot. A rule of thumb is to use 100 to 150 foot of hole for each 12,000 Btu/hr peak load required. Since most residences require around 3 tons of cooling or heating load, up to 450 feet may be required. The national average is 150 to 200 feet per bore. Water with ethylene glycol is circulated in the system. In areas where drilling is difficult or expensive, horizontal closed loops are used; buried four to five feet below the surface. These loops are generally longer than the vertical loops, and use extensive surface land area. In some states, ponds are used as the heat source or heat sink. The pipes are placed on the bottom of the pond, which are generally at least eight feet deep. The Internationsl Ground Source Heat Pump Association, located on the Oklahoma State University Campus at Stillwater, is the main promoter of earth coupled systems.

Recent developments in earth coupled systems use a refrigerant, rather than water/antifreeze, that is circulated through the buried pipes. This system extends the refrigerant loop of the heat pump into the ground, eliminating the heat exchanger and circulation pump between the water/antifreeze loop and the refrigerant loop. The buried copper pipes become a giant evaporator in winter and a condenser in summer. The buried pipes, are placed in 1¼ inch diameter holes, typically 60 feet deep. It normally takes three such holes for each ton (12,000 Btu) of heat pump capacity. Preliminary tests indicate the net effect is a 15 to 20% efficiency gain over water/antifreeze system. (Popular Science, June 1988).

Ground water and earth coupled systems (vertical configuration) depended upon the average ground water temperature. The temperature of the ground and ground water below 100 feet is controlled by the geothermal gradient and thus are considered geothermal. The horizontal earth coupled and surface pond systems are influenced by solar radiation due to their shallow placement. Only data for the former two are considered, and only the ground water systems are used to determine ground water pumping usage. Generally three gallon per minute per ton of heating or cooling load is required. A typical value for a residential location of 3 tons is 8 gpm with a temperature drop of 10 °F.

When calculating energy use, load factors are considered for the heating mode only, since this extracts heat from the earth. In determining the approximate annual energy use, a load factor of 0.10 is used for the southern states with ground water temperature above 60°F; a factor of 0.20 used for the central states, and 0.30 for the northern states where the ground water temperature is below 50°F (See Figure 1). In the southern states, cooling loads control the size of the system, whereas in the northern states heating is the controlling factor. The heating loads for various sites in the U.S. using this procedure are listed in Table 1.

Table 1. -Heating loads for various sites.

State	Site	Temp. (F)	Capacity (Million Btu/h)	Annual Energy (Billion Btu/y)
FL	All of State	75	800.0	700.8
MI	All of State	47	135.0	354.8
IN	All of State	54	187.2	328.0
OH	All of State	53	129.6	227.0
WI	All of State	46	720.0	189.2
IL	All of State	54	100.8	176.6
KY	All of State	59	88.2	154.5
FL	Patrick Air Force Base	72	39.6	138.8
TX	All of State	67	147.9	129.6
PA	All of State	50	68.4	119.8
MN	All of State	45	36.0	94.6
MD	All of State	57	46.8	82.0
NC	All of State	63	91.8	80.4
LA	All of State	69	90.0	78.8
AR	All of State	63	75.6	66.2
VA	All of State	59	36.0	63.1
SC	All of State	67	61.2	53.6
UT	LDS Office Building	60	27.0	47.3
ND	All of State	42	18.0	47.3
MO	All Of State	57	54.0	47.3
NB	Northern Part of State	52	23.4	41.0
NJ	All Of State	55	23.4	41.0
IA	All of State	52	23.4	41.0
DE	All of State	57	20.5	35.9
SD	All of State	47	13.5	35.5
NY	All of State	47	11.2	29.3
GA	All of State	67	24.5	21.4
SD	St. Joseph Indian School	73	7.7	20.6
ID	College of Southern Idaho	102	8.2	18.0
TN	All of State	61	17.6	15.4
KS	All of State	57	8.0	14.0
WA	Clark College	55	6.8	13.8
CO	All of State	52	7.2	12.6
NY	Sagamore Resort	46	4.2	11.0
WA	Grant Country Courthouse	84	3.7	8.4
IN	Corporate Square	55	4.2	7.4
WA	Yakima County Jail	76	3.6	7.3
AL	All of State	67	8.3	7.3
WA	Chinook Tower	60	3.1	6.6
WA	Cowlite Co. Courthouse	55	3.0	6.0
WA	Sundown M Ranch	70	1.8	3.7
MS	All of State	67	4.0	3.5
KS	Elementary Schools (3)	59	4.7	3.3
AZ	All of State	62	3.6	3.2
ND	Buxton School	42	1.2	3.2
OR	Thunderhead Lodge	68	1.2	2.3
NV	Carlin High School	87	0.9	2.0
PA	Factory at Masontown	52	1.0	1.7
NV	Wells High School	87	0.8	1.6
OK	Central Part of State	62	1.2	1.0
MA	English High School	55	0.4	0.9
MS	Mississippi Power Co.	69	1.1	0.9
MS	Commercial Buildings	59	1.1	0.9
NB	Homestead National Monument	58	0.2	0.3
WA	Casey House	70	0.1	0.2
WA	Adams Co. Fire Station	80	0.2	0.2

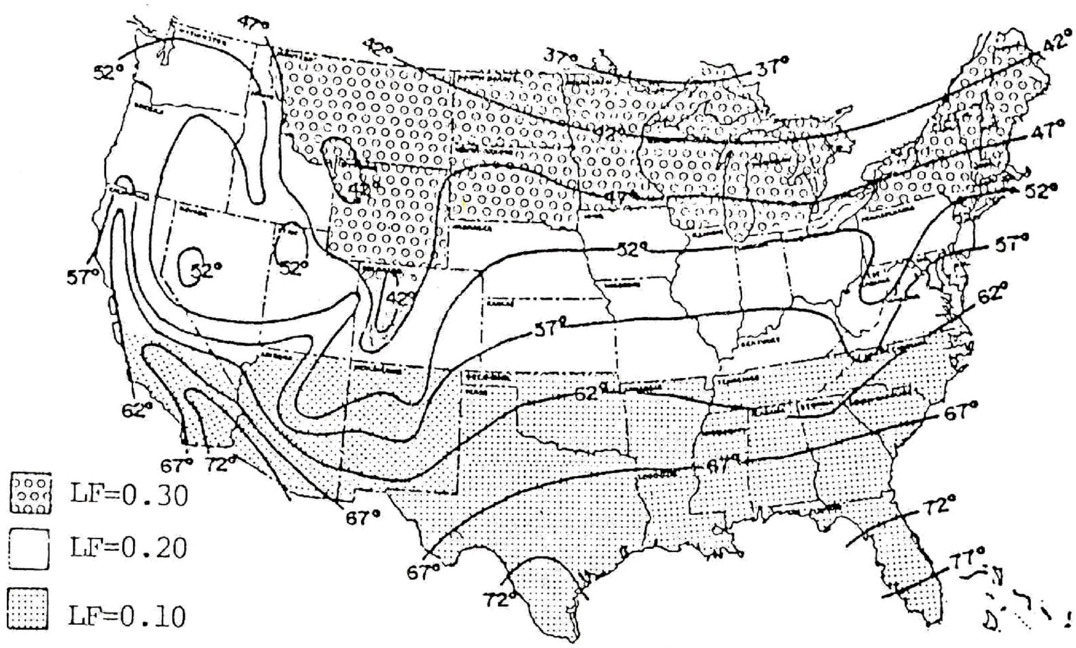

Figure 1. – Average ground water temperature and heating load factor map. Values used for heat pump analysis.

At the present time, earth coupled heat pump systems are being installed in great numbers; however, ground water systems are still popular. It is estimated that almost 50,000 ground water systems and over 30,000 closed loop, earth coupled systems (2/3 of these are vertical installations and 1/3 horizontal) are being used in the United States (mainly in the midwest and east). Over 6,000 earth coupled systems are placed in Canada (Ministry of Energy, Mines and Resources, Ottawa- Solar Division). This year there will be over 10,000 earth coupled and 8,000 ground water systems installed in the United States, a 50% increase over last year. The popularity of these systems is due to the recent promotion by electric utility companies throughout the country, again mainly in the midwest and east. It has national appeal since ground water temperatures down to 39°F can be used in heat pump systems.

It is more difficult to estimate cooling energy than heating energy, as cooling loads depend upon many factors such as solar loads, latent loads, outdoor temperature, and internal loads such as due to lighting and the occupants, rather than on a single major factor found in heating. The equivalent full load hours method is commonly used to estimate the cooling load (ASHRAE). This method is used in the article.

The energy associated with ground and water source heat pumps in the cooling mode can be viewed from two completely different perspectives;1) the energy saves as compared to air source equipment, and 2) the total energy delivered into the ground or ground water. The former savings can be used to estimate energy savings in terms of equivalent barrels of oil after correcting for the efficiency of the plant, etc. The latter is not a savings and has no beneficial use, except that some of it can be extracted during the next heating season by reversing the operation of the heat pump. For many ground water heat pump systems the discharge water is not returned to the ground, but instead disposed of to surface drainage, ponds, pools, or used for watering lawns.

The energy saved as compared to air source equipment is dependent upon the temperature of the ground or ground water as compared to the air, and the equivalent full load hours. The latter number is based on the amount of time cooling is used during an average year converted to an equivalent number of full load hours per year. Southern states would have higher values as compared to northern states; however, northern states would save more energy per operating hour since the colder ground or ground water temperature is more efficient for heat pump operation. Table 2 reports the energy savings for the cooling portion of the heat pumps.

Table 2.-Heat Pump Cooling Load Sites in the United States.

State	Site	Major Appl. Type	Res. Temp (F)	Capacity (tons)	Heat to Ground (billion Btu/y)	Energy Savings (billion Btu/y)
AL	All of State	HP	67	690.0	18.2	0.3
AR	All of State	HP	63	6300.0	185.5	4.1
AZ	All of State	HP	62	300.0	9.3	0.2
CO	All of State	HP	52	600.0	5.6	0.2
DE	All of State	HP	57	1710.0	21.2	0.8
FL	All of State	HP	75	60000.0	1953.0	8.6
FL	Patrick Air Force Base	HP	72	3303.0	107.5	0.5
GA	All of State	HP	67	2040.0	41.1	0.6
IA	All of State	HP	52	1950.0	24.2	1.1
IL	All of State	HP	54	8400.0	143.2	5.7
IN	All of State	HP	54	15600.0	266.0	10.5
IN	Corporate Square	HP	55	350.0	6.0	0.2
KS	All of State	HP	57	600.0	12.1	0.4
KY	All of State	HP	59	7350.0	142.4	4.4
LA	All of State	HP	69	7500.0	244.1	2.7
MA	English High School	HP	55	35.0	0.4	0.0
MD	All of State	HP	57	3900.0	57.4	2.0
MI	All of State	HP	47	11250.0	139.5	7.7
MN	All of State	HP	45	3000.0	27.9	1.6
MO	All of State	HP	57	4500.0	90.7	3.2
MS	All of State	HP	67	300.0	7.9	0.1
MS	Mississippi Power Company	HP	69	89.0	2.5	0.0
MS	Commercial Building	HP	69	84.0	2.3	0.0
NB	All of State	HP	52	1950.0	24.2	1.1
NB	Homestead National Monument	HP	58	14.0	0.3	0.0
NC	All of State	HP	63	7650.0	106.7	2.6
ND	All of State	HP	42	1500.0	11.6	0.7
NJ	All of State	HP	55	1950.0	21.2	0.8
NV	Carlin & Wells High Schools	HP	87	171.0	1.8	0.0
NY	All of State	HP	47	932.0	8.6	0.5
NY	Sagamore Resort	HP	46	350.0	3.2	0.2
NY	East Middle Sch. & C.C	HP	125	0.0	0.0	0.0
OH	All of State	HP	53	10800.0	167.4	7.0
OK	All of State	HP	62	90.0	2.4	0.1
OR	Thunderhead Lodge	HP	68	109.0	1.2	0.0
PA	All of State	HP	50	5700.0	92.8	4.5
PA	Factory	HP	52	80.0	1.4	0.1
SC	All of State	HP	67	5100.0	102.8	1.6
SD	All of State	HP	47	1125.0	15.7	0.9
TN	All of State	HP	61	1470.0	29.6	0.7
TX	All of State	HP	67	12150.0	268.9	4.1
UT	LDS Office Building	HP	60	2250.0	24.4	0.7
VA	All of State	HP	59	3000.0	44.2	1.4
WA	All of State	HP	70	2188.0	23.7	0.2
WI	All of State	HP	46	6000.0	65.1	3.7
			Grand Total	204430.0	4525.1	85.8

Estimation Methods

The energy use reported in Table 1 is primarily developed from personal communication with key persons in each state.

In case of heat pumps wells used for heating, it was assumed that an average residence would require a temperature drop of 10°F at 8 gpm to meet the thermal capacity of an 1,800 ft^2 home.

In Alabama, for example, an estimated 100 heat pump wells are used for space heating. The estimated thermal capacity for the heat load only is:

$$q = (100)\ (8.33\ \text{lbm/gal})(60\text{min/hr})(8\text{gpm})(60°\text{F}-50°\text{F})(1.0\ \text{Btu/lbm/°F})$$

$$q = 4.0 \times 10^6\ \text{Btu/hr}$$

and the estimated annual energy use, based on a load factor of 0.10 for heating only is:

$$AE = (0.10)(8760\ \text{h/yr})(4.0 \times 10^6\ \text{Btu/hr})$$

$$AE = 3.5 \times 10^9\ \text{Btu/yr}$$

The energy savings for ground water heat pump cooling are estimated by the following procedures:

1. Data on three-ton cooling units (the most common size used in the United States) were obtained from the Air Conditioning and Refrigeration Institute (ARI) Directory of Certified Equipment, for a) air source units using 95°F outside air, and b) water source units using ground water at 50°F and 70°F. The latter values were corrected for pumping energy used to lift the water from the well. The average Energy Efficiency Ration (EER) for the air source equipment in the cooling mode is 9.2 Btu/Watt, and for the water source unit 11.1 and 9.5 Btu/Watt respectively (12.3 and 10.4 before correction). The savings, using water source over air source equipment is the difference between the above figures and when converted to a savings of kW/ton is 0.22 kW/ton at 50°F and 0.04 kW/ton at 70°F. The relationship assumed to be approximately linear, thus values at other ground water temperature (not available in ARI) are interpolated.

2. Estimates of Equivalent Full Load Hours were obtained from a list of cities in the 1985 ASHRAE Fundamentals, Chapter 28. The value for each state was obtained by averaging results from cities in the state or from nearby cities of similar weather characteristics.

3. The savings in energy by using a ground water heat pump over an air source heat pump is the savings value in kW/ton based on the average ground water temperature as determined from the map (Figure 1). Using the State of Delaware as an example: average ground water temperature = 57°F giving a savings of 0.16 kW/ton; the equivalent full load hours determined from ASHRAE is approximately 800 hrs/yr; and 570 ground water and earth coupled heat pump installations, each with an average of a three-ton cooling unit. The savings is:

$$(570\ \text{installations})(\ 3\ \text{tons/installations})(800\ \text{hrs/yr})(0.16\ \text{kW/ton})(3413\ \text{Btu/hr-kW})$$

$$=0.75 \times 10^9\ \text{Btu/yr (savings)}$$

4. The heat delivered to the ground or ground water by the heat pump is the sum of the capacity of each installation at three tons (12,000 Btu/hr-ton capacity) plus the compressor energy. The compressor energy varies between 12.3 Btu/Watt at 50°F to 10.4 Btu/Watt at 70°F, or 0.976 kW/ton and 1.154 kW/ton respectively. An average of slightly over 1.00 kW/ton or: (1.00 kW/ton) (3413 Btu/hr kW) = 3500 Btu/hr-ton will be used. Again using the State of Delaware as an example.

(570 installations)(3tons/installations)(800 hrs/yr)(12,000 Btu/hr-ton + 3500 Btu/hr-ton)

= 21.2 x 10^9 Btu/yr (into ground)

In all cases the energy savings is far less than the energy delivered into the ground as shown in Table 2.

Summary of Heat Pump Characteristics

1. **Air source units** as compared to those using heat from the ground are less expensive, and since the technology has been around longer, it is easier to find contractors and installers. They also do not require drilling or excavations to place pipes. The disadvantages are higher operation and maintenance costs and lower efficiency (COP). The outdoor unit is exposed to snow build-up, corrosion (especially critical in the salt air), and vandalism. A backup electrical resistance heating unit is required for heating in colder climates.

2. **Ground Source** (both ground water and earth coupled) units as compared to air source units are more efficient (COP) and provide better performance since the heat source remains at nearly a constant temperature all year. Generally no backup heating unit is required. They have the disadvantage of being more complicated and thus more expensive. They also require drilling or excavation to place the piping. The ground water units require larger bores and casing along with water pumps. Corrosion and water disposal are also a concern.

Some other advantages and disadvantages of these systems are shown in Table 3.
(Ref. DOE/CE/15095-6/ Dec. 1983).

Acknowledgements

Much of the information for this paper was provided by Dan Ellis, President of the International Ground Source Heat Pump Association (IGSHPA), and Vice President of Marketing, Waterfurnace International, Inc., Ft. Wayne, IN; Kevin McCray, National Water Well Association, Dublin, OH; Bob Weaver, Executive Director, IGSHPA, Stilwater, OK; and Harry Braud, Agricultural Engineering Dept., Louisiana State Univ., Baton Rouge, LA.

Table 3.- Advantages and disadvantages of earth-coupled and water-coupled systems.

System	Advantage	Disadvantages
Earth tubes	No energy or low energy consumption	Limited areas where they can be used effectively Moisture, vermin, or radon in tubes may be problems
Earth coil with heat pump	Relatively low energy consumption Moderate operating costs Better performance than air-to-air heat pumps	Dry earth is not as good as water as a source/sink High initial cost leaks difficult to find and repair Pumping cost
Water-coupled system with heat exchanger	Lower initial cost than for heat pump Lower operating cost than for heat pump	Limited areas where they can be used effectively Requires thorough understanding of design factors
Surface water-coupled system with heat pump	Heat source/sink temperatures are relatively constant compared with air Good energy efficiency Moderate operating cost Does not require defrost cycle like air-source heat pump May not require supplemental heat	Suitable water bodies are limited System clogging, fouling, scaling, or corrosion Current or wave action can damage equipment High initial cost Pumping cost
Ground water-coupled system with heat pump	Heat source/sink temperatures are relatively constant Good energy efficiency Does not require defrost cycle like air-source heat pump Moderate operating cost May not require supplemental heat	High initial cost Scaling or corrosion can be problems Pumping cost